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DEM Generation Using Cartosat-I Stereo Data and its Comparison with Publically Available DEM

Sooraj Krishnan[a], N Sajikumar[b]*, Sumam K S[b]

[a]Student, Govt. Engineering College, Trichur, 680009, India
[b]Professor, Govt. Engineering College, Trichur, 680009, India
[b]Professor, Govt. Engineering College, Trichur, 680009, India

Abstract

Cartosat-I or IRS P5 (Indian Remote Sensing Satellite) is a remote sensing satellite meant for cartographic applications like generation of Digital Elevation Model (DEM) and was launched by Inadian Space research organization (ISRO). The paper aims to generate a high quality DEM from Cartosat-I stereo data by means of Leica Photogrammetry Suite (LPS) and thereby comparing the generated DEM with publically available DEMs like ASTER DEM, SRTM DEM and three versions CartoDEMs from NRSC. Results from the study shows that the DEM generated from Cartosat-I stereo data using LPS is more accurate than the publically available Carto DEMs but less accurate than the ASTER and the SRTM DEMs.

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Keywords: Digital Elevation Model (DEM); Cartosat-I; Leica Photogrammetry suite(LPS); CartoDEM

1. Introduction

A Digital Elevation Model (DEM) is a representation of altitude of Earth surface with latitude and longitude i.e. X, Y horizontal coordinates and height Z [1]. The terms Digital Elevation Model (DEM), Digital Terrain Model (DTM) and Digital Surface Model (DSM) are synonymously used in scientific literature. However, the term digital surface model represents the earth's surface and includes all objects like plants and buildings. But,

* Corresponding author. Tel.: +919447828911; fax: +914872336124.
E-mail address: saji@gectcr.ac.in

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the DTM or DEM represents the bare ground surface. Though there are several versions, the suitability of a variety of DEM data for a particular situation depends on the project specifications [2].

DEMs that are available in public domain are ASTER (Advanced Spaceborne Thermal Emission Radiometer Stereoscopy), SRTM (Shuttle Radar Topography Mission) and CartoDEM. Three versions of CartoDEMs are available and these versions can be downloaded from ‘Bhuvan’of (NRSC). Cartosat-I provides stereo data which can be used to generate DEM with higher spatial resolution. However, having higher spatial resolution may not ensure higher accuracy in elevation data. Hence it becomes essential to have an accuracy assessment of DEM generated from different sources, in Kerala where unique topographical features exist. If a DEM with better accuracy can be developed for Kerala, a lot of manpower and money can be saved. Measurement of Ground control points from fields requires a lot time and money. Hence current study is an attempt to verify whether the accurate DEM can be generated without using any Ground Control Points.

National Remote Sensing Agency [3], has published a report on the evaluation of Indian National DEM generated from Cartosat-1 Data. This report provides the overall quality of CartoDEM version 1 in terms of absolute accuracy and a comparison with other globally available DEMs like ASTER and SRTM in terms of accuracy. These are carried out for three test areas, viz, Jagathsinghpur in Orissa, Dharmsala in Himachal Pradesh and Alwar in Rajastan. An accuracy of 8m at 90% confidence level was obtained. Panday and Venkataraman [1] illustrates the generation of DEM from Cartosat-1 data for Chhota Shigri glacier (Himachal Pradesh, India). Leica Programmetry Suite (LPS 9.3) was used in the study to generate Digital Elevation Model. Study mainly highlights the quality of DEM generated for a hilly and glacier covered terrain. Analysis was carried out by generating DEM using Ground Control Points (GCP) and without using GCP. They found that DEM generated using GCP can be used for various applications like landslide study, climatological study and hazard study. Bhardwaj [4] demonstrated the potential of ortho-image (generated from Cartosat-1) in feature extraction and visualization. The study evaluated the accuracy of triangulation and Digital Elevation Model (DEM). The study area is taken as Jaipur city in Rajasthan. It is observed that accuracy of DEM generated from Cartosat-1 Stereo data could be improved by using good distribution of GCP's. However, collection of ground control points is an expensive affair especially when large area to be covered. Moreover, the accuracy of the generated DEM may depend on the terrain and topographical features. Such an accuracy has not been assessed in the Kerala region where unique feature of topography exists. Hence it becomes essential to compare the accuracy of publically available DEM with that of Carto DEM for this region. In this study, DEM from Cartosat-I stereo data is compared with publically available Cartosat-I DEM version 1, version 2 and version 3 and also other DEMs like ASTER and SRTM. The accuracy assessment by taking field measurement is carried out for categorically assessing the usefulness of the Cartosat I data and publically available DEM as against the already available DEM. This assessment can give an indication of how accurate currently available DEMs like SRTM DEM, ASTER DEM and CartoDEMs for general purposes. As indicated earlier, it is essential to assess the accuracy of the DEM from stereo data without using ground control points because the collection of control points requires a lot of money and time.

2. Study Area

Thrissur district is in the central region of Kerala state lying between 10° 10’ and 10° 46’ north latitude and 75° 57’ and 76° 54’ east longitude. Fifteen scenes of Cartosat-I stereo images are required for covering the entire Thrissur district. Out of the many scenes available, the one surrounding the Government Engineering College is selected. For DEM generation and evaluation purposes, one scene of Cartosat-I satellite imagery is acquired from National Remote Sensing Centre (NRSC), Hyderabad, covering the western most part of Thrissur district. This scene covers an area lying between 10° 43’ and 10° 25’ north latitude and 76° 11’ and 76° 26’ east longitude and is shown in (Fig.1).

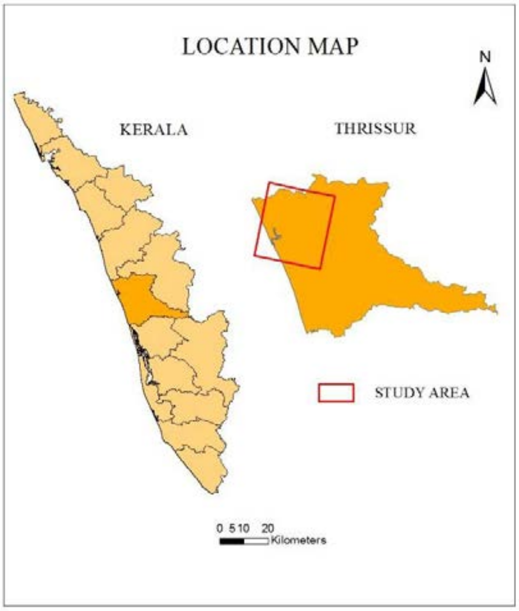

Fig.1. Location Map

3. Data Used

3.1. Satellite Imagery

Cartosat-I stereo orthokit product of the study area, is acquired from the NRSC. Ortho kit products are supplied with WGS84 ellipsoid as datum and with only radiometric corrections done. An orthokit product consists of an image file (GeoTIFF format), a Rational Polynomial Coefficient (RPC) text file and a metadata file. General characteristics of the Cartosat-I stereo orthokit product used in this study is shown in Table 1.

3.2. DGPS Survey

Differential Global Positioning System (DGPS) is used in the study to accurately measure the coordinates and elevation data of the selected points. Twenty seven points are acquired with UTM Projection and WGS84 datum. These accurate data of the selected points are needed to compare the elevation values extracted from the DEM generated from Cartosat-I stereo data and publically available DEMs like SRTM, ASTER and CartoDEMs.

Table 1. Details of Product acquired from NRSC

	Band A	Band F
Product number	15306631102	15306631101
Satellite ID	P5	P5
Sensor Path-Row	PAA 0540-346	PAF 0540-346

Date, Time and Scene Id.	21JAN07 05:27:43FA2SR100	21JAN07 05:27:43FA2SR100

4. Methodology

4.1. DEM Generation

Leica Photogrammetry Suite (LPS), ERDAS Imagine 2013 software is used to generate DEM from Cartosat-I stereo pairs. The method of generating DEM in LPS includes following steps: Creating a new block file, Adding the frame and Editing the frame, Providing Rational Polynomial Coefficients (interior and exterior orientation), Computing Pyramid Layers, Generating automatic tie points, Triangulation and Generating DEM

DEM generation process in LPS, using satellite data starts with creating a block file, defining geometric model as ‘Rational Functions’ and then a frame is added. Added frame is edited by providing Rational Polynomial Coefficients. Cartosat-1 stereo scenes are provided with Rational Polynomial Coefficient (RPC) files. The Rational Polynomial Coefficient (RPC) file contains the third degree polynomial coefficients. These coefficients relate the image to the object space accounting for the imaging sensor geometry. Rational Polynomial satellite sensor models are simple and empirical mathematical models relating image space (line and column position) to latitude, longitude, and surface elevation. The name Rational Polynomial derives from the fact that the model is expressed as the ratio of two cubic polynomial expressions [5].

Tie points are the points whose ground coordinates are not known but they can be identified in the overlapping areas of the images. Software selects a matching point in one image, finding its conjugate point in the other image; these points are called automatic tie points. DTM can be extracted using tie points only. Such an attempt is tried to verify whether one can develop better quality DEM directly from the satellite stereo pair without collecting additional data (i.e. only using tie points obtained from the imagery) for the region under concern.

Block triangulation is the process of defining the mathematical relationship between the images obtained in the sensor model and the ground. Once the relationship has been defined, information concerning the Earth’s surface and orthorectified images can be created. Triangulation is to be done by using tie points. The error in the computation is calculated by the root mean square error and is defined as square root of mean square error computed with reference to tie points. Thus calculated RMSE error should be less than one (sub pixel accuracy), in order to get good accuracy for the DEM. Digital terrain model (DTM) extraction can be performed after complete setup of the block file [6].

4.2. DEM Comparison

Digital Elevation Model (DEM) that is generated using Leica Photogrammetry Suite is assessed for elevation accuracy, by comparing the elevation values of the DEM with the corresponding DGPS values and elevation values in publically available DEMs like SRTM, ASTER and CartoDEMs. The SRTM data can be downloaded from USGS EROS centre and ASTER from Earth Remote Sensing Data Analysis Centre (ERSDAC). Three versions of CartoDEMs are available in ‘Bhuvan’, of National Remote Sensing Centre (NRSC). Then the elevation values of the 27 control points from each DEMs, including DEM generated using LPS were extracted using ArcGIS software. These extracted values are then compared with measured values from DGPS.

5. Results and Discussions

5.1. DEM Generation

DEM is generated using tie points. Tie points are generated automatically. 116 tie points are generated automatically and triangulation is carried out. The resulting RMSE from the triangulation is 0.272. Once triangulation is over, the DEM is extracted using DTM extraction tool. The extracted DEM is shown in Fig.2.

Fig.2. DEM Generated using LPS

5.2. DEM Comparison

The elevations of 27 field points, for which actual elevations had been collected, were extracted from SRTM, ASTER, CartoDEM version 1, version 2 and version 3 by using 'Extract values from points' in the spatial analyst tool box of ArcGIS. Similarly, these elevations are extracted from DEMs generated using Leica Photogrammetry Suite and are shown in the Table 2**.** Elevation values of CartoDEMs including the one generated using LPS) show that, CartoDEMs have negative elevation value. The negative elevation has occurred due to the change in datum. All these (CartoDEM and DEM generated with tie points) uses the datum based on geoid, while the other two uses the datum based on spheroid. ASTER and SRTM DEMs use spheroid as the datum and hence the elevation obtained will be positive and corresponds to reduced level with respect to MSL. Data for GCP are taken using DGPS, which uses datum based on spheroid and hence in the processing, the datum is taken as spheroid based. Hence, for the sake of comparison, all the values are to be reduced to the same datum.

Table 2. Elevation Values of 27points

Sl.No.	Point	DGPS	D_LPS	CARTV1	CARTV2	CARTV3	SRTM	ASTER
1	base1	30.809	-40.007977	-70	-68	-68	26	26
2	base2	24.315	-56.084557	-68	-74	-74	13	19

3	base3	18.172	-50.990841	-77	-71	-71	9	23
4	300	13.314	-59.10606	-86	-84	-84	11	9
5	301	15.071	-59.243652	-104	-91	-91	2	8
6	302	9.108	-63.03331	-92	-88	-88	4	5
7	400	24.783	-55.794537	-75	-79	-79	18	16
8	401	12	-71.991562	-91	-95	-95	5	6
9	402	11.047	-70.647942	-90	-93	-93	8	5
10	403	11.126	-72.922974	-90	-89	-89	-2	12
11	404	9.947	-71.932388	-91	-88	-88	-3	13
12	405	10.805	-69.293457	-89	-87	-87	-3	7
13	406	10.567	-65.681252	-86	-86	-86	6	8
14	407	100.504	19.997068	-2	-4	-4	122	81
15	408	139.261	52.554871	34	33	33	131	118
16	409	33.232	-48.935089	-62	-68	-68	42	20
17	410	20.102	-58.405849	-84	-78	-78	15	15
18	411	13.849	-69.091515	-91	-85	-85	2	13
19	412	20.496	-59.776524	-80	-76	-76	14	14
20	413	12.681	-62.870365	-88	-87	-87	5	7
21	500	14.897	-55.87915	-83	-78	-78	8	15
22	501	30.04	-42.687386	-68	-65	-65	19	24
23	502	5.799	-59.085812	-90	-87	-86	5	10
24	503	8.685	-57.874245	-86	-81	-81	10	20
25	504	8.122	-50.667866	-93	-87	-89	2	9
26	505	20.199	-55.354664	-83	-78	-78	20	24
27	506	11.161	-47.738644	-84	-79	-79	10	23

(DGPS - Measured Elevation at Ground Control points using Differential Global Positioning System;D_LPS-DEM Generated using LPS; CARTV1-CartoDEM Version 1; CARTV2- CartoDEM Version 2; CARTV3-CartoDEM Version 3; SRTM- SRTM DEM; ASTER- ASTER DEM)

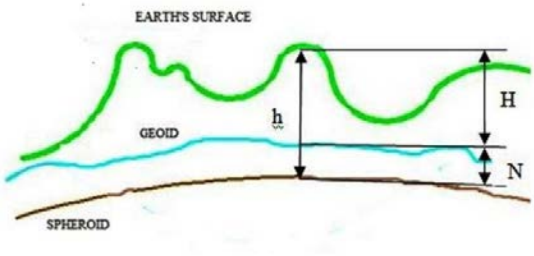

Fig.3. Geiod and Spheroid

GeoidEval, an online geoid converter which reads the positions on standard input, and prints out the corresponding heights of the geoid above the WGS84 spheroid [7]. Required inputs for the software are latitude, longitude and DGPS elevation (h). GeoidEval uses Earth Graviational Model 2008 (EGM 2008) to find the geoid height (N). EGM 2008 is a spherical harmonic model of the Earth's gravitational potential. Orthometric height (H) is the height above the imaginary surface called the geoid. Height above the spheroid datum (h) of the 27 points can be found out by using Eqn.1.

$$h = H + N \tag{1}$$

Table 3 shows the comparison of elevation of DEMs generated from Cartosat-I stereo data (once converted WGS84 datum) and publically available DEMs. Table 4 shows the RMSE of elevation of 27 points of each DEM. Highest error occurred in CartoDEM Version 1 with an RMSE of 60.94 and least for ASTER DEM with an RMSE of 8.13. Comparing the CartoDEMs and the DEM generated from Cartosat-I stereo data using LPS, DEM generated using LPS shows better accuracy than publically available CartoDEMs. However, these values are much above the RMSE of ASTER and SRTM DEMs. Hence the DEM generation using tie points alone cannot be considered as a viable method for getting high quality DEMs. Hence the necessary better quality DEM can be generated only by collecting ground control points which in turn increase the cost of production of DEMs. Such a methodology shall be resorted to only if a better quality DEM can be obtained.

Table 3. Elevation comparison

Sl.No.	Point	DGPS(h)	Geoid Height (N)	D_LPS	CARTV1	CARTV2	CARTV3	SRTM	ASTER
1	base1	30.809	39.5741	-0.433877	-30.4259	-28.4259	-28.4259	26	26
2	base2	24.315	39.5218	-16.562757	-28.4782	-34.4782	-34.4782	13	19
3	base3	18.172	39.5773	-11.413541	-37.4227	-31.4227	-31.4227	9	23
4	300	13.314	39.6749	-19.43116	-46.3251	-44.3251	-44.3251	11	9
5	301	15.071	39.7366	-19.507052	-64.2634	-51.2634	-51.2634	2	8
6	302	9.108	39.7633	-23.27001	-52.2367	-48.2367	-48.2367	4	5
7	400	24.783	39.5195	-16.275037	-35.4805	-39.4805	-39.4805	18	16
8	401	12	39.6068	-32.384762	-51.3932	-55.3932	-55.3932	5	6
9	402	11.047	39.6498	-30.998142	-50.3502	-53.3502	-53.3502	8	5
10	403	11.126	39.6259	-33.297074	-50.3741	-49.3741	-49.3741	-2	12
11	404	9.947	39.6584	-32.273988	-51.3416	-48.3416	-48.3416	-3	13
12	405	10.805	39.6809	-29.612557	-49.3191	-47.3191	-47.3191	-3	7
13	406	10.567	39.6799	-26.001352	-46.3201	-46.3201	-46.3201	6	8
14	407	100.504	39.4614	59.458468	37.4614	35.4614	35.4614	122	81
15	408	139.261	39.4468	92.001671	73.4468	72.4468	72.4468	131	118
16	409	33.232	39.3927	-9.542389	-22.6073	-28.6073	-28.6073	42	20
17	410	20.102	39.478	-18.927849	-44.522	-38.522	-38.522	15	15
18	411	13.849	39.5956	-29.495915	-51.4044	-45.4044	-45.4044	2	13
19	412	20.496	39.5627	-20.213824	-40.4373	-36.4373	-36.4373	14	14
20	413	12.681	39.6257	-23.244665	-48.3743	-47.3743	-47.3743	5	7
21	500	14.897	39.5672	-16.31195	-43.4328	-38.4328	-38.4328	8	15
22	501	30.04	39.5962	-3.091186	-28.4038	-25.4038	-25.4038	19	24
23	502	5.799	39.7411	-19.344712	-50.2589	-46.2589	-46.2589	5	10
24	503	8.685	39.6387	-18.235545	-46.3613	-41.3613	-41.3613	10	20
25	504	8.122	39.6429	-11.024966	-53.3571	-49.3571	-49.3571	2	9

26	505	20.199	39.4421	-15.912564	-43.5579	-38.5579	-38.5579	20	24
27	506	11.161	39.5169	-8.221744	-44.4831	-39.4831	-39.4831	10	23

Table 4. RMSE Comparison

Sl.No.	TYPE OF DEM	RMSE
1	D_LPS	36.79
2	CARTV1	60.94
3	CARTV2	58.87
4	CARTV3	58.90
5	SRTM	8.98
6	ASTER	8.13

6. Conclusion

The current study evaluated the accuracy of Digital Elevation Models (DEM) generated from Cartosat-I stereo data using Leica Photogrammetry Suite, 2013 and publically available DEMs by acquiring accurate ground elevation data using Differential Global Positioning System (DGPS). DEM is generated using automatically generated tie points. RMSE in triangulation is found to be 0.274 which is desirable for DEM extraction. The DEM that is generated using LPS from Cartosat-I stereo pair is of better quality than any of the publically available CartoDEMs. The RMSE of elevation of DEM generated using LPS is of the order of 36.79, which is on a higher side. On the other hand, the RMSE obtained for ASTER and SRTM are at the order 8.13 and 8.98 respectively. Hence, the DEM generated using tie points alone cannot be considered as a viable method for getting high quality DEMs for the region under concern. Thus the necessary better quality DEM can be generated only by collecting ground control points which in turn increase the cost of production of DEMs. These ground control points are to be used for developing the DEMs. However, this increase in the cost can be justifiable only if better accuracy above that of SRTM and ASTER DEMs can be expected.

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